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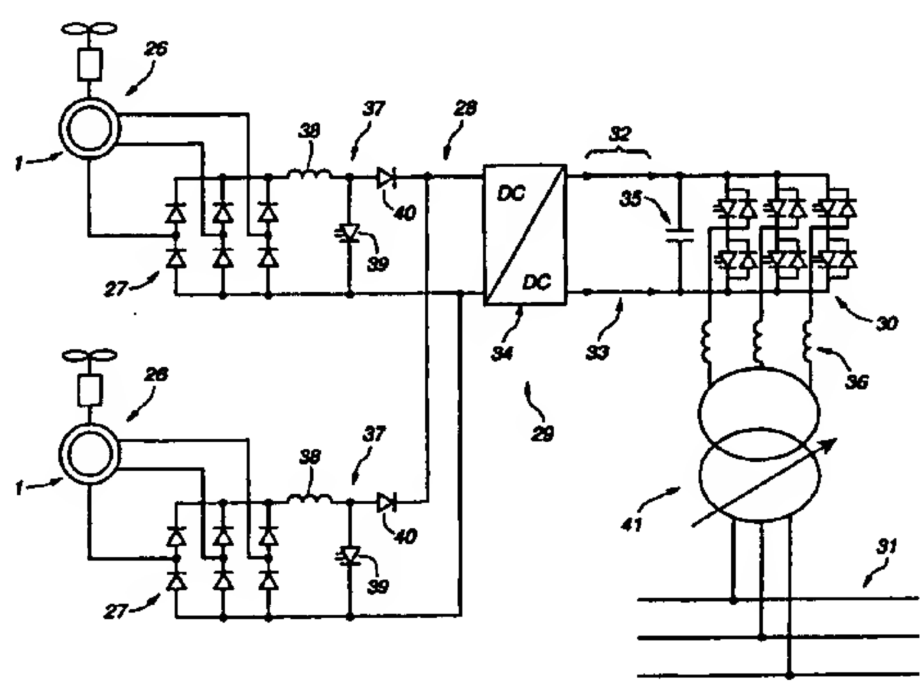

(57) **Abstract:** A wind power plant comprising at least one wind power station (26), which includes a wind turbine, an electric generator (1) driven by this wind turbine and a rectifier (27), and an electric direct voltage connection (29) between the rectifier arranged at the wind power station and an inverter (30), the alternating voltage side of which is connected to a transmission or distribution network (31), the inverter being arranged on the network side of the plant. An underwater cable (33) or the like being included in the direct voltage connection (29). The plant comprises a DC/DC-converter (34) having a low voltage side electrically connected to the rectifier (27) and a high voltage side electrically connected to the inverter (30). The inverter (30) is arranged on the wind power station side of the underwater cable (33). With advantage, several wind power stations (26) are parallel connected on the low-voltage side of the DC/DC-converter (34).

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A WIND POWER PLANT

FIELD OF THE INVENTION

This invention relates to a wind power plant comprising at least one wind power station, which comprises a wind turbine, an electric generator driven by this wind turbine and a rectifier, and an electric direct voltage connection between the rectifier arranged at the wind power station and an inverter, the alternating voltage side of which is connected to a transmission or distribution network, the inverter being arranged on the network side of the plant.

The invention is preferably intended to be used in such cases where the connection between the generator and the transmission or distribution network includes a cable intended to be submerged into water. Consequently, expressed in other words, it primarily relates to such applications where one or several wind turbines with associated generators are intended to be placed in seas or lakes, wherein the cable connection extends to the transmission or distribution network placed on land. Even though the advantages of the invention in the following primarily will be dealt with in connection with location of the wind turbines in seas or lakes, the invention can, however, also imply advantages in cases where the wind turbines and the generators are located on land and the connection, which in that case not necessarily has to consist of a cable but instead can be realized in the form of aerial lines or cables, connects several such wind

turbines/generators with the transmission or distribution network.

BACKGROUND OF THE INVENTION AND PRIOR ART

When locating wind power at sea it is required, in order to get economy in the project, that large groups of wind power stations are being located within a limited area. Sea based wind power requires relatively large wind power stations (3MW and above) and a suitable total system power of 50-100 MW is expected. So far the planning of such wind parks has presupposed that the electrical power transmission is effected by traditional alternating current transmission in three-phase alternating voltage sea cable systems. In that case, the generator is almost always a three-phase asynchronous generator. It is true that there are examples where synchronous generators have been used directly connected to the network, but this has as a rule resulted in that a complicated mechanical spring suspension has had to be installed between the generator and the engine house in order to dampen power variations caused by the varying character of the wind load. This depends on the fact that the rotor dynamics of a synchronous generator mechanically behaves like a spring against a stiff alternating voltage network, whereas an asynchronous generator behaves like a damper. A conventional asynchronous generator of 3 MW could presumably be made for about 3-6 kV and be connected in series with a transformer which steps up the voltage to, let us say 24 kV, in a first step. In a wind power park with 30-40 wind power stations there would then be provided a central transformer which further steps up the voltage to 130 kV. The advantage with such a system is that it is cheap and does not require any complicated sub-systems. The disadvantage partly lies in the difficulties to technically transmit power over long distances in a high-voltage alternating voltage cable. This depends on the fact that the cable produces capacitive reactive power, which increases with the length. The current through the conductor and in the cable shield then in-

creases so much that the cable cannot be realized for long distances. The other disadvantage lies in that the varying wind load causes voltage variations on the transmission line, which could affect the power consumers that are connected nearby. This applies in particular if the network is "weak", i.e. has a low short-circuiting power. Due to the abovementioned technical problems with long cable transmission distances, one might be forced to connect the wind park to a "weak" network. According to certain guiding principles, the voltage variation may not be more than 4%. Different countries have different regulations and as a rule the regulations are mitigated in case of a lower voltage level on the transmission line. Voltage variations could also have to be treated differently depending on time intervals. Rapid voltage variations causes "flicker", i.e. light variations in glow lamps, which is regulated in rules.

A solution to the problem above with long cable distances is to transmit the power with high-voltage direct voltage. The cable can then be drawn right up to a strong network. Another advantage is that DC-transmissions have lower losses than AC-transmissions. From a technical point of view the cable distance can then be of unlimited length. A HVDC-link consists of a rectifier station, a transmission line (cable or aerial line), an inverter station and filters for removing overtones generated during the conversion. In an older variant of HVDC-links thyristors are used for rectification and inversion. Thyristors can be switched on but not switched off; the commutation takes place at the zero-crossing of the voltage, which is determined by the alternating voltage, and the converters are therefore called line commutating. A disadvantage with this technique is that the converters consume reactive power and cause current overtones, which are sent out in the network. In a more modern direct voltage solution, IGBT:s are used instead of thyristors in the converters. An IGBT (Insulated Gate Bipolar Transistor) can be switched on as well as switched off and furthermore has a high switch frequency. This implies that the converters can be produced ac-

cording to a completely different principle, so called self-commutating converters. To sum up, the advantages with self-commutating converters are that they can deliver as well as consume reactive power, which makes possible an active compensation of the voltage level on the network side if the network is weak. Consequently, this makes this type of converter superior to the older technique in the way that it can be connected to a network being situated closer to the wind power. The high switch frequency also leads to a reduction of the problem with overtones as compared with the older generation of HVDC. A disadvantage is, however, that the losses in the converter station are higher as well as the price. A self-commutating converter is characterized in that the voltage is built up by a rapid pulse pattern, which is generated by the converter. The voltage difference between the pulse pattern and the sinusoidal network voltage will lie above the inductances on the network side. There are two types of self-commutating inverters; a voltage stiff, VSI (Voltage Source Inverter) and a current stiff, CSI (Current Source Inverter), with somewhat different characteristics. VSI, which has at least one capacitor on the DC-side, has the best power regulation.

There have been built some experimental wind power stations using technique resembling the HVDC-concept, but for a completely different reason, namely for achieving a variable rotational speed of individual wind power stations. The generator of the wind power station is then disconnected from the network via a DC-link on low voltage, typically the 400 V or 660 V level. A variable rotational speed on the turbine gives energy gains at the same time as it as a rule results in that the variations of rotational speed can be used for eliminating the rapid power pulsations, which cause “flicker”. However, it is of course not possible to eliminate the slow power changes, which are inherent in the nature of the wind load. The moment of inertia of the turbine could be said to function as an intermediate storage for kinetic energy. In such a system a synchronous generator is not to any

disadvantage, but rather to an advantage, since the asynchronous generator requires a more expensive and more complicated rectifier. If it is desired to have a direct driven generator and consequently eliminate the need of a gear unit between the turbine and the generator, the generator must be synchronous since it will be provided with so many poles. In other words, a direct driven generator requires a DC-intermediate link. In the concept it is also possible to actively regulate the moment by changing the trigger angle, if a controlled rectifier is used. In most concepts having a variable rotational speed, an external active rotational speed control is furthermore provided by so called pitch control, which implies that the blade angle is changed on the turbine. A disadvantage with a variable rotational speed according to the related concepts is the price of the required power electronics and furthermore that the maintenance of such power electronics out at sea will be difficult and costly.

In WO 97/45908 a technical solution is suggested, which combines the good characteristics of a variable rotational speed system with the advantages of a HVDC-link of older model. By parallel connecting the wind power stations already in the DC intermediate link (see Fig 3 in said document) a number of N low-voltage inverters and one high-voltage rectifier are eliminated. According to this suggestion a rectifier with choke is to be used on the wind power turbine side and a central inverter with associated choke is to be used on the network side. The system seems at first hand to be intended for line commutated, or in any case current stiff, rectifiers and inverters, since the chokes in the direct voltage link makes this current stiff. This has an advantage, namely that the DC-voltage after the rectifier can be varied within a large range. This is necessary in case of operation with variable rotational speed, since the generator in the wind power station at low rotational speeds only can deliver a low output voltage. However, a disadvantage with a current stiff inverter is that it cannot regulate the reactive power through

the network as effectively as a voltage stiff inverter. Furthermore, it appears that the inverter in a direct current manner is to be connected in series with the parallel connected rectifiers in the wind power stations. This implies that the same direct current is output from the wind park as is input to the inverter on land. Furthermore, it appears that the voltage is presupposed to be on 6-10 kV, which is the typical voltage for conventional generators. This implies that the DC-voltage will be about 12 kV, which is an unrealistic low DC-voltage for transmitting a total power of 50 MW. The losses in the cable will be very large. For a wind park of the size 50-100 MW it would instead be necessary to transmit the power on a voltage level of about 100 kV. It is true that this would be possible if a transformer would be connected to each generator and a sufficient number of valves would be series connected in all rectifiers. However, if it is possible to avoid the transformer in the wind power station this would be a great advantage. Furthermore, to series connect the number of valves required for rectifying N output voltages for N wind power stations to 100 kV DC-voltage is associated with big problems.

PURPOSE OF THE INVENTION

The purpose of the invention is to achieve, with a more simple and cheap system for variable rotational speed, the same good power transmission from a sea-based wind park to the land-based network as offered by a modern HVDC-system, with the possibility to eliminate the necessity of transformers and controlled power electronics in the wind power stations. This is very valuable since all maintenance carried out at sea is costly and difficult to perform. A further purpose of the invention is to be able to have such a high voltage on the DC-transmission that low losses are obtained also for a large wind park, for instance on 50-100 MW.

SUMMARY OF THE INVENTION

The purpose of the invention is achieved primarily through the features defined in the characterizing part of the subsequent claim 1. The unsolved problem of prior technique that the DC-voltage will be too low is consequently solved by connecting the DC/DC-converter out at sea with its low-voltage side electrically connected to the rectifier and its high-voltage side electrically connected to the inverter. Such a DC/DC-converter functions in about the same way as a transformer for DC; it steps up the direct voltage a factor n:1 and steps down the direct current as 1:n, where n is the conversion. This implies that the inverter and the rectifier are no longer connected in series.

According to a preferred embodiment, the rectifier is formed as a passive diode rectifier in series with a local step-up direct voltage converter. This is a more simple system than a line commutated rectifier and is considered to operate better at high voltages. The local step-up direct voltage converter suitably consists of a choke, a series connected IGBT-valve and a series connected diode. This can also be the basic design of a DC/DC-converter.

Furthermore, it is preferred that the inverter is constituted by a voltage stiff, self-commutated system, the characteristics of which are superior to a line commutated system from a power regulating point of view. Such a system is characterized, in an embodiment of the invention, in that at least one capacitor is connected in parallel over the inverter on the DC-link and that inductances are connected in series with each phase on the network side. In a preferred embodiment, the valves are constituted by series connected IGBT:s.

With the generator technology of today concerning wind power stations, it is possible to produce a generator which can handle 10 kV, but higher voltages than that would be desirable. Fur-

thermore, the conventional insulation technology for stator windings is sensitive to temperature variations, humidity and salt, which a wind turbine generator is exposed to.

According to a particularly preferred embodiment of the invention, a solid insulation is used for at least one winding in the generator, which insulation preferably is performed according to the subsequent claim 14. The winding has more specifically the character of a high-voltage cable. A generator manufactured in this way, creates the prerequisites of achieving considerably higher voltages than conventional generators. Up to 400 kV can be achieved. Furthermore, such an insulation system in the winding implies insensibility to salt, humidity and temperature variations. The high output voltage implies that transformers can be completely excluded, which implies avoidance of the already mentioned disadvantages such as increase in costs, reduction in effectivity, risks of fire and risks for the environment. The latter are due to the fact that conventional transformers contains oil.

A generator having such a winding formed by a cable can be produced by threading the cable in slots performed for this purpose in the stator, whereupon the flexibility of the winding cable implies that the threading work can be easily performed.

The two semiconducting layers of the insulation system have a potential compensating function and consequently reduce the risk of surface glow. The inner semiconducting layer is to be in electrically conducting contact with the electrical conductor, or a part thereof, located inwardly of the layer, in order to obtain the same potential as this. The inner layer is intimately fastened to the solid insulation located outwardly thereof and this also applies to the fastening of the outer semiconducting layer to the solid insulation. The outer semiconducting layer tends to contain the electrical field within the solid insulation.

In order to guarantee a maintained adherence between the semiconducting layers and the solid insulation also during temperature variations, the semiconducting layers and the solid insulation have essentially the same thermal coefficient of expansion.

The outer semiconducting layer in the insulation system is connected to ground potential or otherwise a relatively low potential.

In order to achieve a generator capable of very high voltage, the generator has a number of features which have already been mentioned above and which distinctly differ from conventional technology. Further features are defined in the dependent claims and are discussed in the following:

Features which have been mentioned above and other essential characteristics of the generator and consequently of the wind power plant according to an embodiment of the invention comprise the following:

- The winding in the magnetic circuit is produced of a cable having one or several permanently insulated electrical conductors with a semiconducting layer at the conductor and outwardly of the solid insulation. Typical cables of this kind are cables having an insulation of cross-linked polyethylene or ethylene-propene, which for the purpose here in question are further developed concerning stands of the electrical conductor and also the character of the insulation system.

- Cables having a circular cross section are preferred, but cables having another cross section can also be used, for instance in order to achieve a better packing density.

- Such a cable makes it possible to design a laminated core of the magnetic circuit in a new and optimal way as concerns slots and teeth.

- Advantageously, the winding is produced with a stepwise increasing insulation or the best utilization of the laminated core.

- Advantageously, the winding is produced as a concentric cable winding, which makes it possible to reduce the number of coil end crossings.

- The shape of the slots is adapted to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings extending axially and/or radially outwardly of each other and having constrictions running between the layers of the stator winding.

- The shape of the slots is adapted to the cable cross section in question and to the stepwise changing thickness of the insulation of the winding. The stepwise insulation makes it possible for the magnetic core to have an essentially constant tooth width independent of the radial extension.

- The abovementioned further development concerning the cores implies that the winding conductor consisting of a number of layers brought together, i.e. insulated strands, does not necessarily have to be correctly transposed, and non-insulated and/or insulated from each other.

- The abovementioned further development concerning the outer semiconducting layer implies that the external semiconducting layer is cut off at suitable points along the length of the cable and each cut-off partial length is directly connected to ground potential.

The use of a cable of the type described above makes it possible that the hole length of the outer semiconducting layer of the cable, as well as other parts of the plant, can be kept at ground potential. An important advantage is that the electrical field is close to zero in the coil end region outwardly of the outer semiconducting layer. With ground potential on the outer semiconducting layer the electric field does not have to be controlled. This implies that there will occur no field concentrations neither in the core, nor in the coil end regions or in the transition section between them.

The mixture of insulated and/or non-insulated strands packed together, or transposed strands, results in low eddy current losses. The cable can have an outer diameter in the order of 10-40 mm and a conductor area in the order of 10-200 mm^2.

According to a further embodiment, a transformer with variable transmission is arranged on the high voltage side of the inverter.

Further advantages and features of the invention will appear in the following and from the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the subsequent drawings, a closer description of embodiments of the invention given as examples will follow below. In the drawings:

Fig 1 is a schematic axial end view of a sector of the stator in an electric generator in the wind power plant according to the invention.

Fig 2 is an end view, partly cut, of a cable used in the stator winding according to Fig 1,

Fig 3 is a schematic view, partly in section, of an embodiment of a wind power generator according to the invention,

Fig 4 is a schematic view showing the embodiment of the wind power plant according to the invention, and

Fig 5 is a schematic perspective view showing an embodiment of a transformer with variable transformation.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With the aid of Figs 1-3 the design of the generator 1 preferred in an embodiment of the invention is first explained. Fig 1 shows a schematic axial view through a sector of the stator 2. The rotor of the generator is denoted as 3. The stator 2 is in a conventional way formed of a laminated core. Fig 1 shows a sector of the generator corresponding to a pole pitch. From a yoke section of the core, located furthest out in radial direction, a number of teeth 5 extend radially inwards towards the rotor 3 and these teeth are separated by a slot 6, in which the stator winding is arranged. Cables 7 forming this stator winding are high-voltage cables which can be of essentially the same type as those used for power distribution, i.e. PEX-cables (PEX = cross-linked polyethylene). A difference is that the external mechanically protecting PVC-layer and the metal shield normally surrounding such a power distribution cable have been eliminated so that the cable for the present invention only comprises the electrical conductor and at least one semiconducting layer on each side of an insulating layer. The cables 7 are schematically illustrated in Fig 1, wherein only the electrically conducting central part of each cable section or coil side is shown. It appears that each slot 6 has a varying cross section with alternating broad parts 8 and narrow parts 9. The broad parts 8 are essentially circular and surround the cable, waist sections between the broad parts forming the narrow parts 9. The waist sections serve to radially fix the position of each cable. The cross section of the slot 6 be-

comes narrower radially inwards. This depends on that the voltage in the cable sections are lower the closer they are situated to the radially innermost part of the stator 1. Thinner cables can therefore be used inwards, whereas thicker cables are required further out. In the illustrated example, cables with three different dimensions and arranged in three correspondingly dimensioned sections 10, 11, 12 of the slot 6 are used. A winding 13 for auxiliary power is arranged furthest out in the slot 6.

Fig 2 shows a stepwise cut end view of a high-voltage cable for use in the generator. The high-voltage cable 7 comprises one or several electrical conductors 14, each of which comprises a number of strands 15, which together give a circular cross section. The conductors can for instance be of copper. These conductors 14 are arranged in the middle of the high-voltage cable 7 and in the shown embodiment each of the conductors is surrounded by a partial insulation 16. It is however possible to omit the partial insulation 16 on one of the conductors 14. In the shown embodiment the conductors 14 are surrounded by a first semiconducting layer 17. Around this first semiconducting layer 17 there is an insulation layer 18, e.g. of PEX-insulation, which in its turn is surrounded by a second semiconducting layer 19. Consequently, the concept "high-voltage cable" does not, in this application, have to comprise any metal shield or any external protective layer of the type normally surrounding a power distribution cable.

In Fig 3 a wind power station is shown with a magnetic circuit of the type described with reference to Figs 1 and 2. The generator 1 is driven by a wind turbine 20 via a shaft 21. Even though the generator 1 can be direct driven by the turbine 20, i.e. that the rotor of the generator is coupled fixed in rotation to the shaft of the turbine 20, there can be a gearing 22 between the turbine 20 and the generator 1. This can for instance be constituted by a single-step planetary gearing, the purpose of which is to change up the rotational speed of the generator in relation to the rota-

tional speed of the turbine. The stator 2 of the generator carries the stator windings 23, which are built up of the cable 7 described above. The cable 7 can be unsheathed and pass on into a sheathed cable 24 via a cable joint 25.

In Fig 4, which in a schematic form broadly illustrates the wind power plant, two wind power stations 29 connected in parallel are illustrated, each having a generator 1. The number of wind power stations can of course be larger than two. Furthermore, a rectifier 27 is comprised in each wind power station 26. The parallel connection of the wind power stations takes place at the point indicated with 28.

An electric direct voltage connection is present between the rectifiers 27 arranged at the wind power stations 26 and an inverter 30, the alternating voltage side of which is connected to a transmission or distribution network. The inverter 30 is arranged on the network side of the plant. This normally implies that the inverter 30 is located on land relatively close to the transmission or distribution network 31. However, the wind power stations 26 including the generators and the rectifiers 27 are located at sea on suitable foundations. The direct voltage connection 29 comprises a section denoted as 32 in Fig 4, which section in practice can be very long. Along this section there is, consequently, a connection part 33, which is critical in regard of losses. In the preferred embodiment of the invention, this connection part 33 is considered to be formed of an underwater cable, namely in the case that the wind power stations 26 are situated out at sea or in a lake. However, the connection part 33 can also be formed of one or several aerial lines or cables.

The plant comprises a DC/DC-converter 34 having a low-voltage side electrically connected to the rectifiers 27 and a high-voltage side electrically connected to the inverter 30. The DC/DC-converter 34 is arranged on the wind power station side of the plant. Expressed in other words, this implies that the previously

discussed connection part 33 is situated between the DC/DC-converter 34 and the inverter 30. In practice, the converter 34 is considered to be placed on one of the foundations that are carrying one of the wind power stations 26 or alternatively there can be a particular foundation for the converter 34. Independent of which type of foundation the converter 34 is placed on, the foundation in question is also provided with bus-bars in order to parallel connect the occurring wind power stations.

The converter 34 is arranged in such a way that it operates as a direct voltage increaser, i.e. that the direct voltage in the connection part 33 between the converter 34 and the inverter 30 is intended to be, through the converter, higher and suitably substantially higher than the voltage on the input side of the converter 34.

It is preferred that the inverter 30 is a voltage stiff self-commutated inverter. A capacitor 35 is parallel connected over the DC-link of the inverter 30.

The inverter 30 suitably has network inductances 36 connected in series with each phase on its network side. It is preferred that the inverter comprises series connected IGBT:s.

According to a preferred embodiment, the generators are synchronous generators with permanent magnetized rotors.

With advantage, the rectifiers 27 are passive rectifiers. This eliminates the necessity of active power control electronics out at sea. As passive rectifiers, diode rectifiers are preferred. These diode rectifiers 27 are in series with a local step-up direct voltage converter 37. In a preferred embodiment, each separate converter 37 comprises a choke, a series connected IGBT-valve 39 and a series connected diode 40. The converter 34 could be formed like such a step-up direct voltage converter.

In Fig 5, a preferred embodiment according to the invention of a transformer with variable transmission is illustrated. The advantage with this transformer is that its windings are provided with a solid insulation in a similar manner as already described with respect to the generator with reference to Figs 1 and 2. Consequently, the transformer windings are correspondingly built up with an insulation system comprising at least two semiconducting layers 17, 19, each of which constitutes essentially equipotential surfaces, and the solid insulation 18 is situated between these semiconducting ,layers. Consequently, in the transformer according to Fig 5 the windings will also have the character of flexible cables. On the whole, all the features of the winding cable according to Fig 2 related to above in connection with the generator apply, with the exception that the outer semiconducting layer 19, in the transformer phase, does not have to be cut up in parts along the length of the cable in order to ground these parts each by itself. The advantage of such a transformer with a solid insulation resides in a substantial improvement in effectivity in that the electrical field essentially will be kept inside the outer semiconducting layer, and furthermore the important advantage is achieved that the inflammable and ecologically harmful oil occurring with conventional transformers is eliminated.

In Fig 5, the transformer is illustrated in a principle form for one of the phases in question. Men skilled in the art will of course realize that, in the case of a multi-phase embodiment, cores having more limbs than two and associated yoke can entail that all the phase windings are placed on one and the same core. However, it is of course also possible to use a separate core for each phase in a transformer of this type.

Consequently, a transformer core consisting of a yoke and two limbs is illustrated in Fig 5, a main winding 43 being applied around one of the limbs and a control winding 44 being arranged around the other limb. The main winding can either be consti-

tuted of a primary winding or a secondary winding. Consequently, the control winding 44 is used for varying the transformation of the transformer. The control winding 44 is arranged in the form of winding turns wound onto a drum 45, which drum is rotatable about the core limb in question. The drum 45 is driven by means of a suitable, not shown motor, e.g. via belt driving. Consequently, the control winding 44 is functioning as a variable coil. The number of winding turns on the control winding drum 45 is varied by means of a rotatable storage drum 46 for the winding 44. The winding drum 46 is also motor-driven in a suitable way. In Fig 5 it is illustrated how an end section 47 of the control winding is grounded. This end section 47 is stationary and is in electrically conducting connection with the control winding 44 on the drum 45 via a slipring contact device of a kind known per se. There is a winding section 48 also in connection with the storage drum 46, which winding section is stationary and which is intended to be connected to the electrical equipment in question. In order to electrically connect the winding section 48 with the control winding section received on the winding drum, a corresponding slipring contact device is provided.

From the description above, it appears that the transmission of the transformer can be varied rapidly and to a desired degree by rotating the drums 45 and 46 so that a desired number of control winding turns are present on the drum 45. A prerequisite in this connection is that the control winding 44 is formed of the previously described, flexible high-voltage cable having solid insulation.

The invention is of course not only limited to the described embodiments. Several detail modifications are consequently possible and realized by men skilled in the technical field as soon as the basic inventional idea has been presented. Such detail modifications and equivalent embodiments are included within the scope of the subsequent claims.

Claims

1. A wind power plant comprising at least one wind power station (26), which includes a wind turbine (20), an electric generator (1) driven by this wind turbine and a rectifier (27), and an electric direct voltage connection (29) between the rectifier (27) arranged at the wind power station and an inverter (30), the alternating voltage side of which is connected to a transmission or distribution network (31), the inverter being arranged on the network side of the plant, ***characterized*** in that it comprises a DC/DC-converter (34) having a low voltage side electrically connected to the rectifier (27) and a high voltage side electrically connected to the inverter (30), and that the DC/DC-converter (34) is arranged on the wind power station side of the plant.

2. A device according to claim 1, ***characterized*** in that the inverter (30) is a voltage stiff self-commutated inverter.

3. A plant according to claim 1 or 2, ***characterized*** in that a capacitor (35) is parallel connected over the DC-link of the inverter (30).

4. A plant according to any of claims 1-3, ***characterized*** in that the inverter (30) on its network side has network inductances (36) connected in series with each phase.

5. A plant according to any of the preceding claims, ***characterized*** in that the inverter (30) comprises series connected IGBT:s.

6. A plant according to any of the preceding claims, ***characterized*** in that the generator (1) is a synchronous generator with permanent magnetized rotor.

7. A plant according to claim 6, ***characterized*** in that generator (1) is direct driven by the wind turbine without gear unit.

8. A plant according to any of the preceding claims, ***characterized*** in that the rectifier (8) is a passive diode rectifier.

9. A plant according to claim 7 or 8, ***characterized*** in that a step-up direct voltage converter (37) is arranged in series with the passive rectifier (27) on the low-voltage side of the DC/DC-converter (34).

10. A plant according to claim 9, ***characterized*** in that the step-up direct voltage converter (37) comprises a choke (38), at least one series connected IGBT-valve (39) and at least one series connected diode (40) series connected.

11. A plant according to any of the preceding claims, ***characterized*** in that several wind power stations (26), each comprising a wind turbine (20), a generator (1) and a rectifier (27), are parallel connected on the low-voltage side of the DC/DC-converter (34).

12. A plant according to claim 11 and any of claims 9 and 10, ***characterized*** in that each wind power station (26) comprises a local step-up direct voltage converter (37).

13. A plant according to any of the preceding claims, wherein the generator (1) comprises at least one winding (7), ***characterized*** in that the winding is provided with a solid insulation (18).

14. A plant according to claim 13, ***characterized*** in that the winding comprises an insulation system comprising at least two semiconducting layers (17, 19), each of which essentially constitutes equipotential surfaces, and that the solid insulation (18) is located between these semiconducting layers.

15. A plant according to claim 14, ***characterized*** in that at least one of the semiconducting layers (17, 19) has essentially the same thermal coefficient of expansion as the solid insulation (18).

16. A plant according to any of claims 13-15, ***characterized*** in that the winding is formed of a high-voltage cable (7).

17. A plant according to any of claims 14-16, ***characterized*** in that the innermost (17) of the semiconducting layers has essentially the same potential as an electric conductor (14) located inwardly of this layer.

18. A plant according to claim 17, ***characterized*** in that the inner one (17) of the semiconducting layers is in electrically conducting contact with the conductor (14) or a part thereof.

19. A plant according to any of claims 14-18, ***characterized*** in that the outer one (19) of the semiconducting layers is connected to a potential being fixed in advance.

20. A plant according to claim 19, ***characterized*** in that the fixed potential is ground potential or otherwise a relatively low potential.

21. A plant according to any of the preceding claims, ***characterized*** in that the direct voltage connection (30) comprises a cable (33) intended to be submerged into water or one or several aerial lines or cables.

22. A plant according to any of the preceding claims, ***characterized*** in that a transformer (41) with variable transformation is arranged on the network side of the inverter (30).

23. A plant according to claim 22, ***characterized*** in that the transformer with variable transformation comprises at least one

core (41) and a control winding (44) around the core, and that the transformer comprises means for transmission of a variable part of the control winding to or from at least one storage means (46).

24. A plant according to claim 23, ***characterized*** in that the control winding is arranged on a rotatable control winding drum (45).

25. A device according to any of claims 23-24, ***characterized*** in that the storage means (46) comprises a rotatable storage drum.

26. A plant according to any of claims 22-25, ***characterized*** in that the winding(-s) (43, 44) of the transformer is (are) formed of a flexible cable having a solid insulation.

27. A plant according to claim 26, ***characterized*** in that the insulation is included in an insulation system, which besides the solid insulation comprises at least two semiconducting layers, each of which constitutes essentially equipotential surfaces, the solid insulation being located between these semiconducting layers.

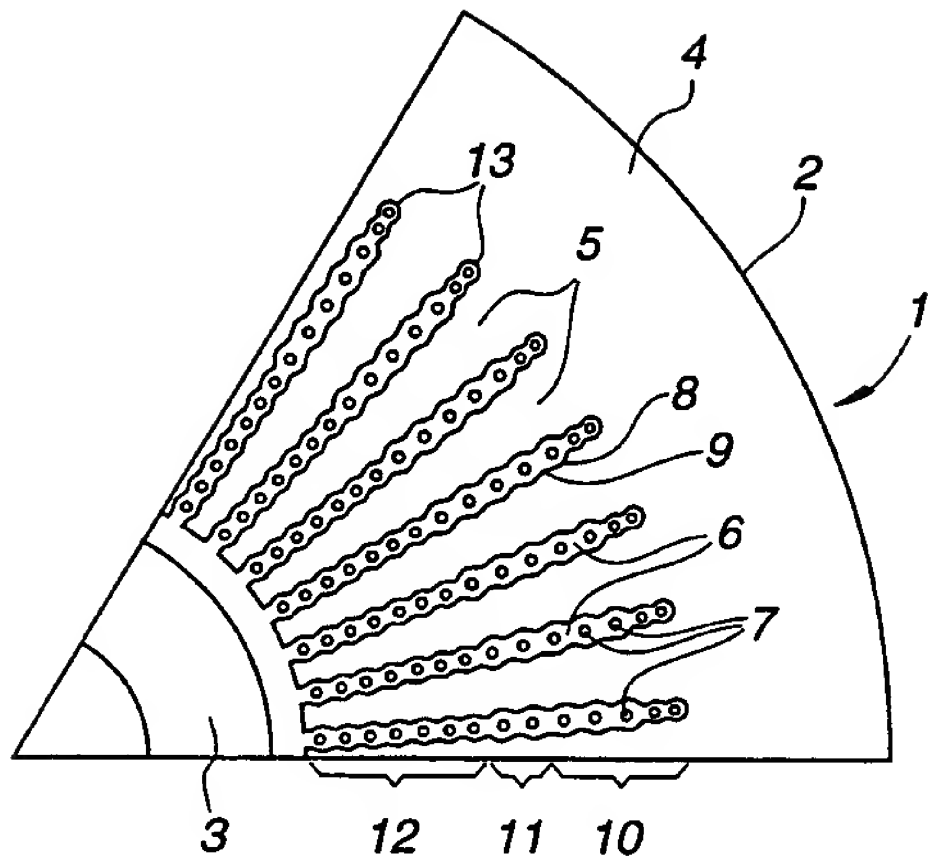

Fig. 1

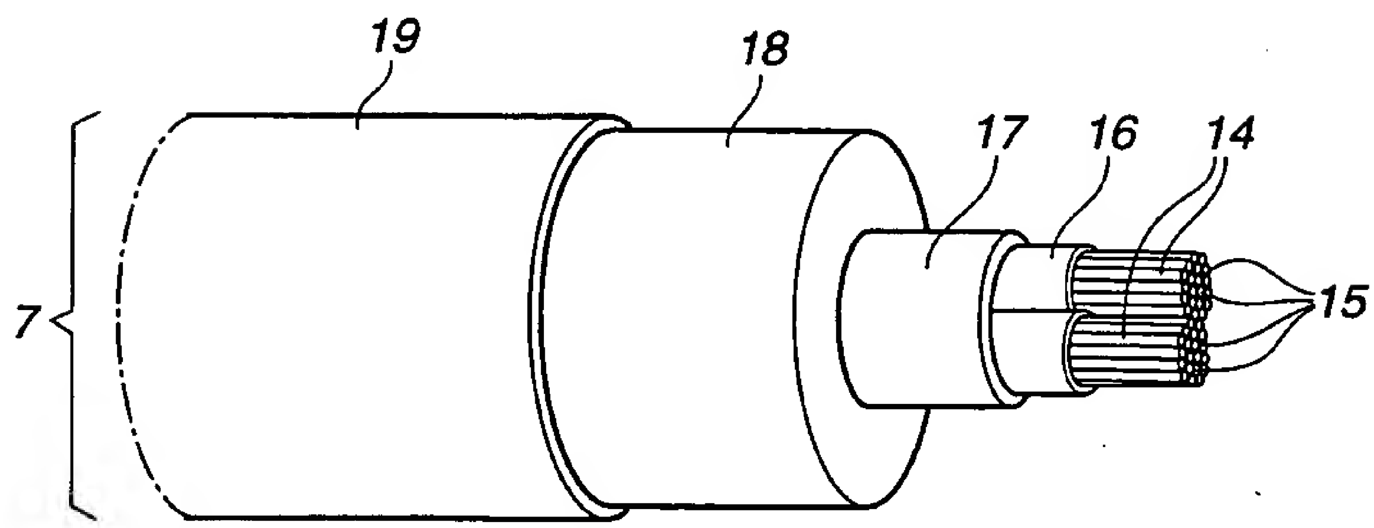

Fig. 2

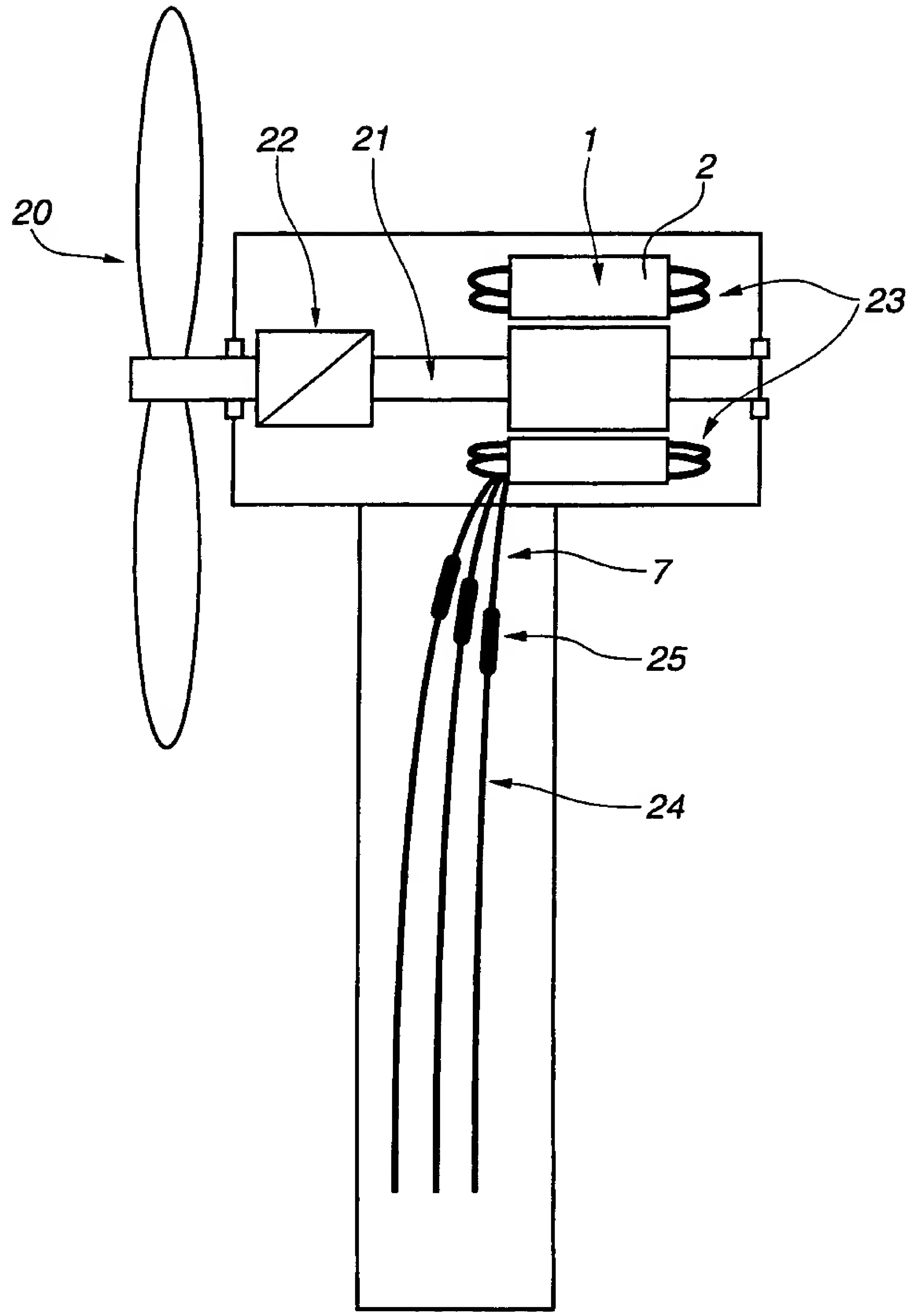

Fig. 3

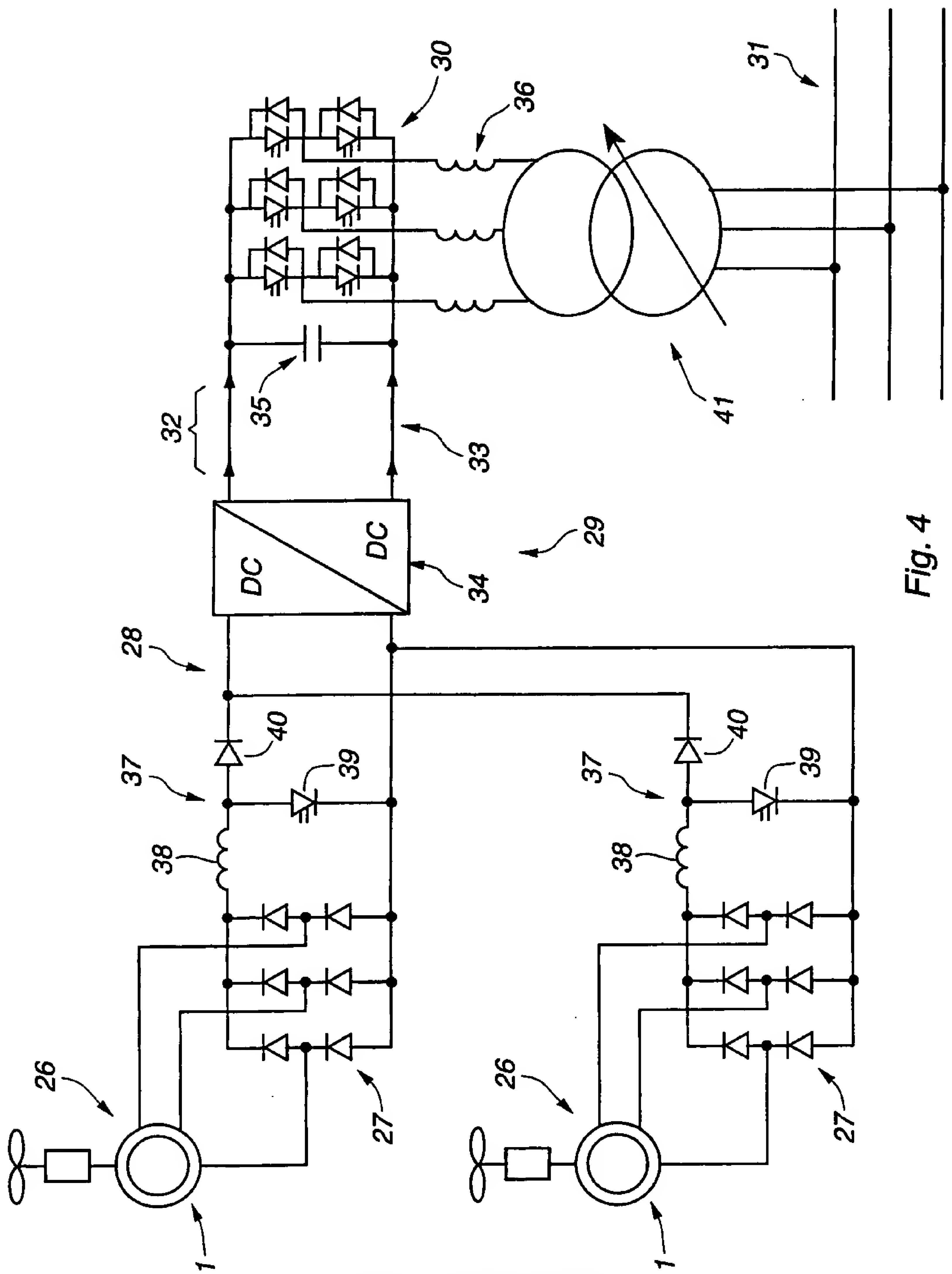
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Fig. 4

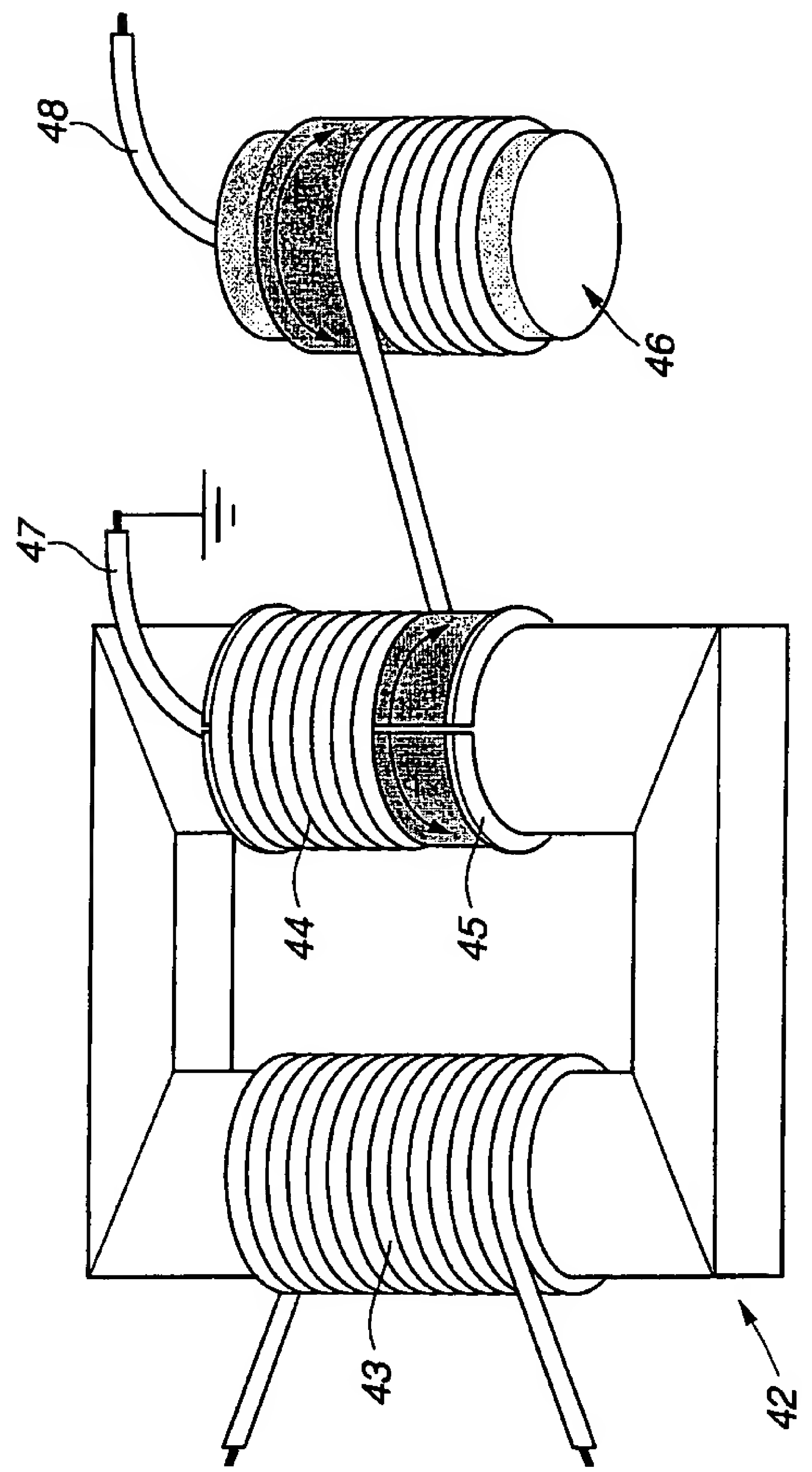

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/00943

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H02J 3/36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
D,A	WO 9745908 A1 (SIEMENS AKTIENGESELLSCHAFT), 4 December 1997 (04.12.97), figure 3, abstract --	1-27
A	WO 9843336 A2 (ASEA BROWN BOVERI AB), 1 October 1998 (01.10.98), page 7, line 1 - line 10, figure 1 --	1-27
A	US 5499178 A (NED MOHAN), 12 March 1996 (12.03.96), column 13, line 5 - line 31, figure 8 -- --------	1-27

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 2000	22-02-2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Tomas Erlandsson/mj Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SE 99/00943

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9745908 A1	04/12/97	DE 19620906 A	08/01/98
		EP 0939995 A	08/09/99
WO 9843336 A2	01/10/98	AU 3468797 A	21/01/98
		CA 2218942 A	24/09/98
		EP 0909354 A	21/04/99
		SE 9701060 A	04/03/98
		SE 9703329 A	25/09/98
		US 5980095 A	09/11/99
US 5499178 A	12/03/96	WO 9418683 A	18/08/94
		EP 0617858 A	05/10/94
		JP 7502160 T	02/03/95
		US 5345375 A	06/09/94
		WO 9312576 A	24/06/93